Electrothermal Simulation
FLOORS

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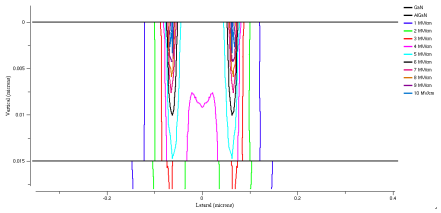
Scientific Approach

FLOORS



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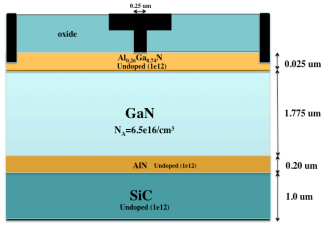
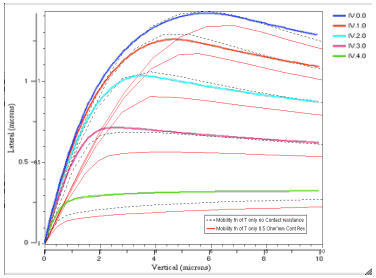


Electric Field Development

Device Structure Development

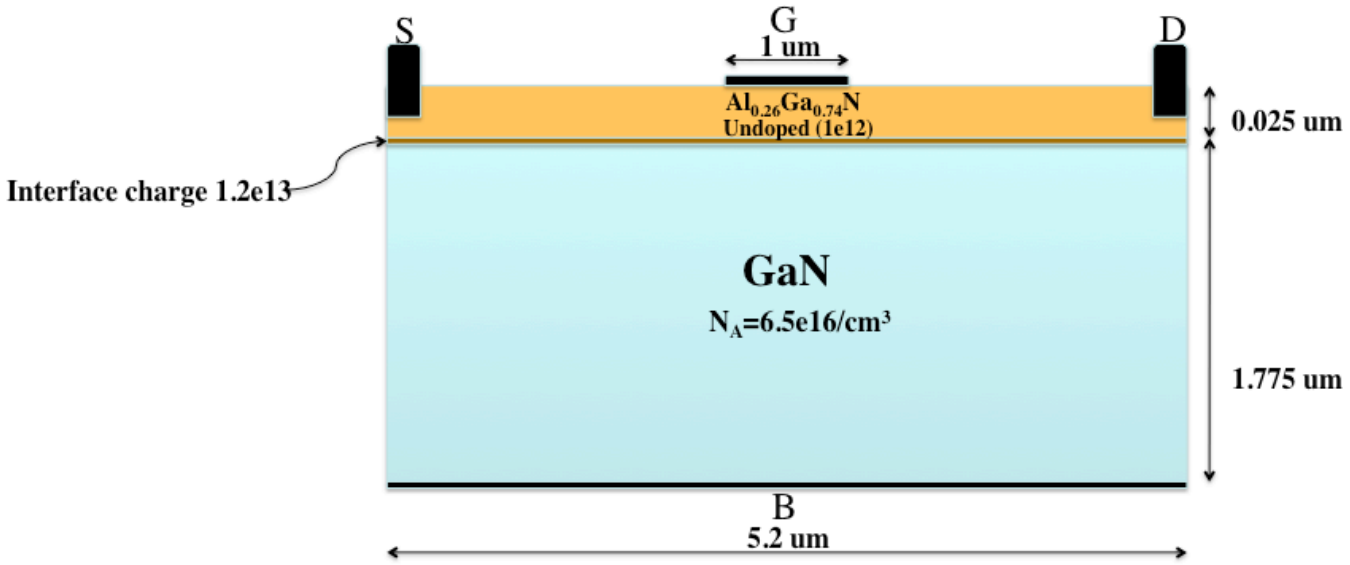


Model & Simulation Calibration

Electrothermal Simulation

- Overview
  - Progress with HEMT structure
  - Simulation comparisons with E. Heller/SDevice
  - Current and future work

HEMT Structure Development



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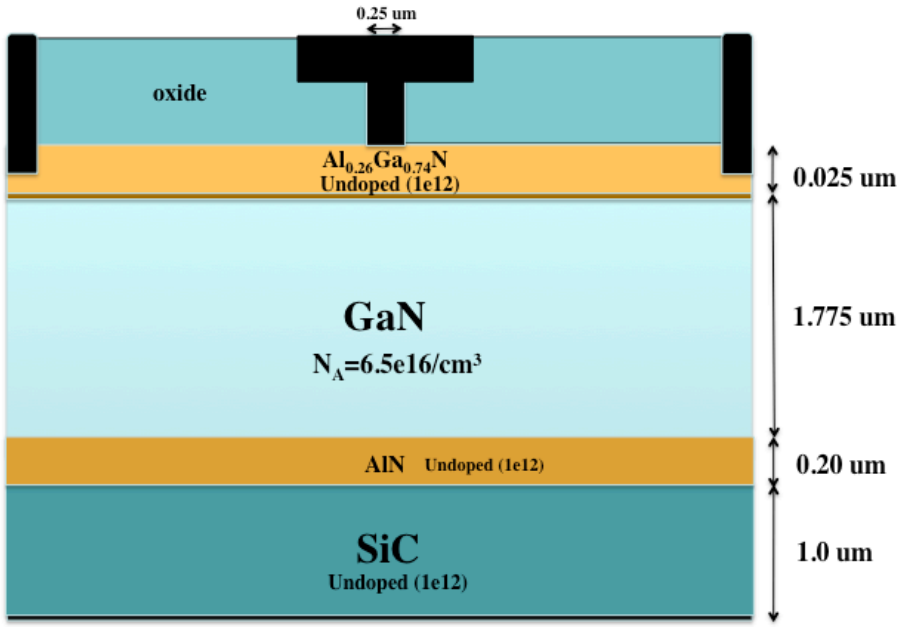
- At the last review
  - AlGaN/GaN structure only; AlN and SiC in development
  - Simple gate contact

New HEMT Structure



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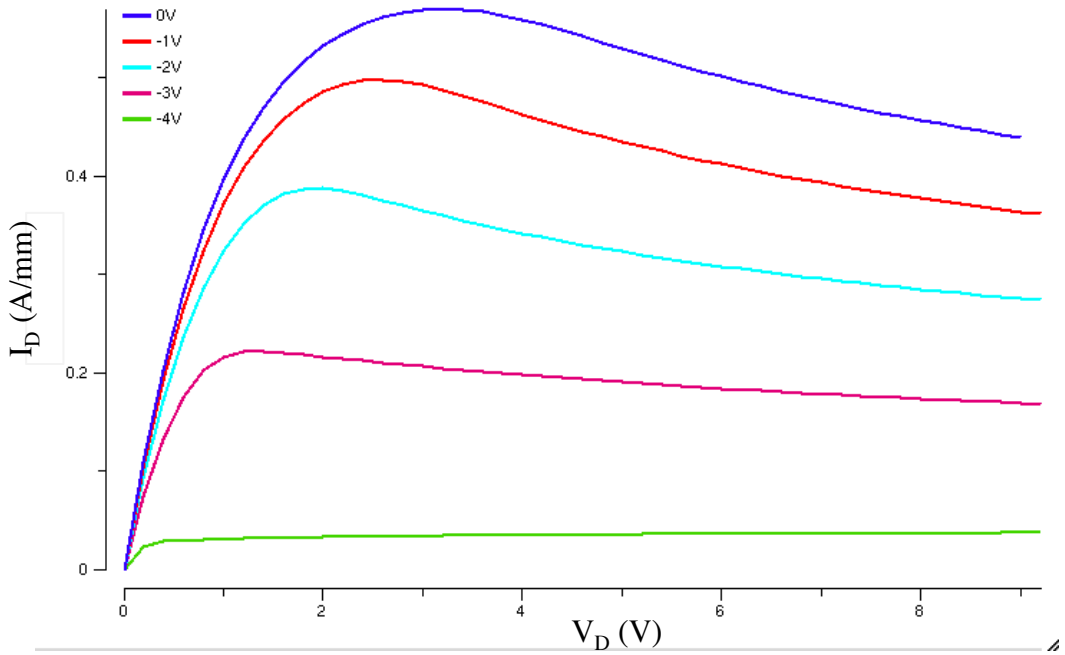
- AlN and SiC successfully added
  - Fully functional, some parameters need tweaking
  - Traps/defects can be added to AlN
- T-shaped gate created for first time in FLOORS
  - Metal surrounded by oxide

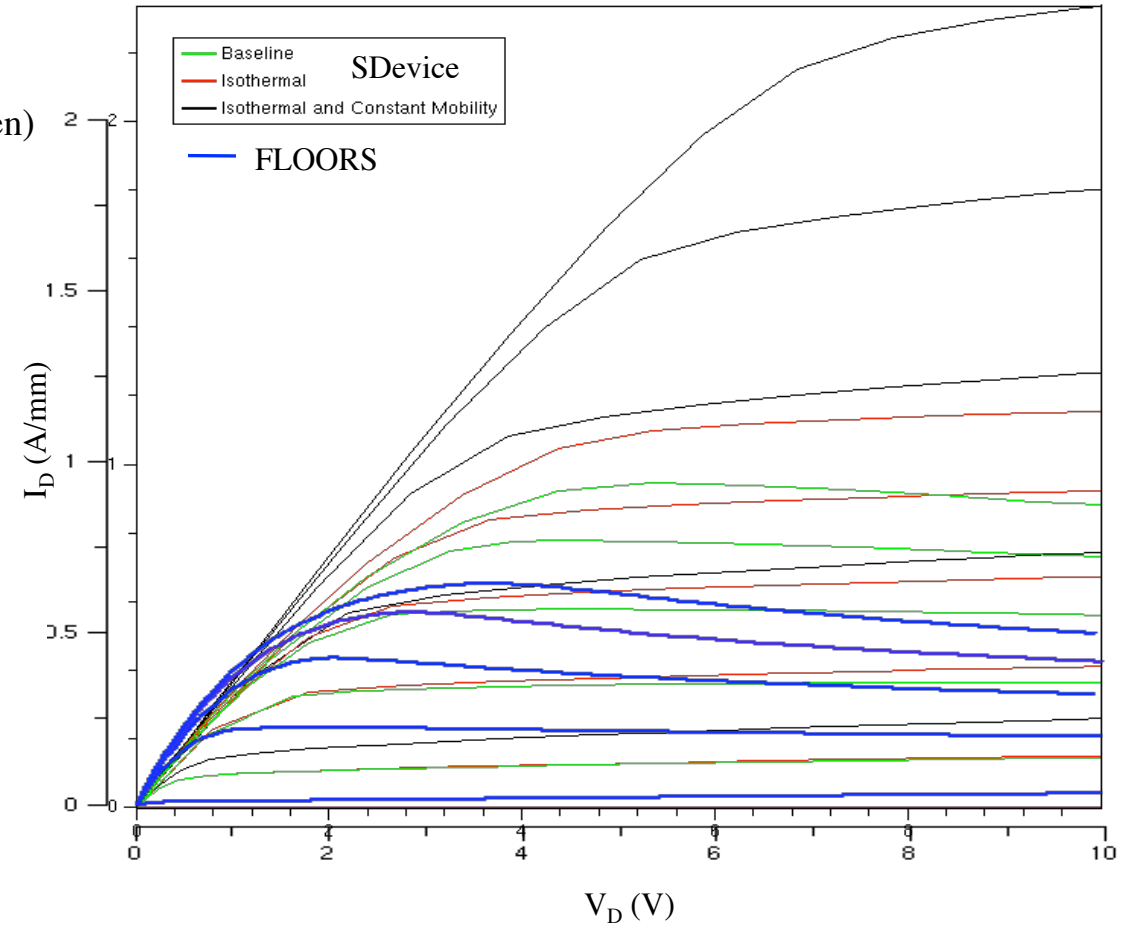
I_D vs. V_D Curves for Initial Model



- Convergence and reasonable IV plot
  - T-gate, all materials, E_F, low and high field μ, temp-dependence for all parameters
- Ready to compare with Heller/SDevice and calibrate simulations

IV Comparison with Heller simulations

- V_G=0 to -4V, V_D=0 to 10V
  - Heller: SDevice, "Baseline" curves (green)
  - FLOORS (blue)
- FLOORS I_D and V_D ~30% too low
- Contact resistance difference for V_D
  - Calculated as
    - V_S=0V+(0.5Ω*0.881A)=0.4405V
    - V_G=0V
    - V_D=10V-(0.5Ω*0.881A)=9.5595V
  - Translates to
    - V_S=0V
    - V_G=-0.4405V
    - V_D=9.1190V



SDevice and FLOORS Model Comparison

- GaN Low Field Mobility

SDevice: $\dfrac{1630}{\left(\dfrac{T}{300}\right)^{1.88}}$

FLOORS: $$\mu_0(T,\,N) = \mu_{\min}\left(\frac{T}{300}\right)^{\beta_1} + \frac{(\mu_{\max}-\mu_{\min})\left(\dfrac{T}{300}\right)^{\beta_2}}{1+\left[\dfrac{N}{N_{ref}\left(\dfrac{T}{300}\right)^{\beta_3}}\right]^{\alpha(T/300)^{\beta_4}}}$$

- GaN High Field Mobility

SDevice: $\dfrac{\mu_{low}}{\left(1+\left(\dfrac{\mu_{low}*E}{v_{sat}}\right)^{\beta}\right)^{\frac{1}{\beta}}}$

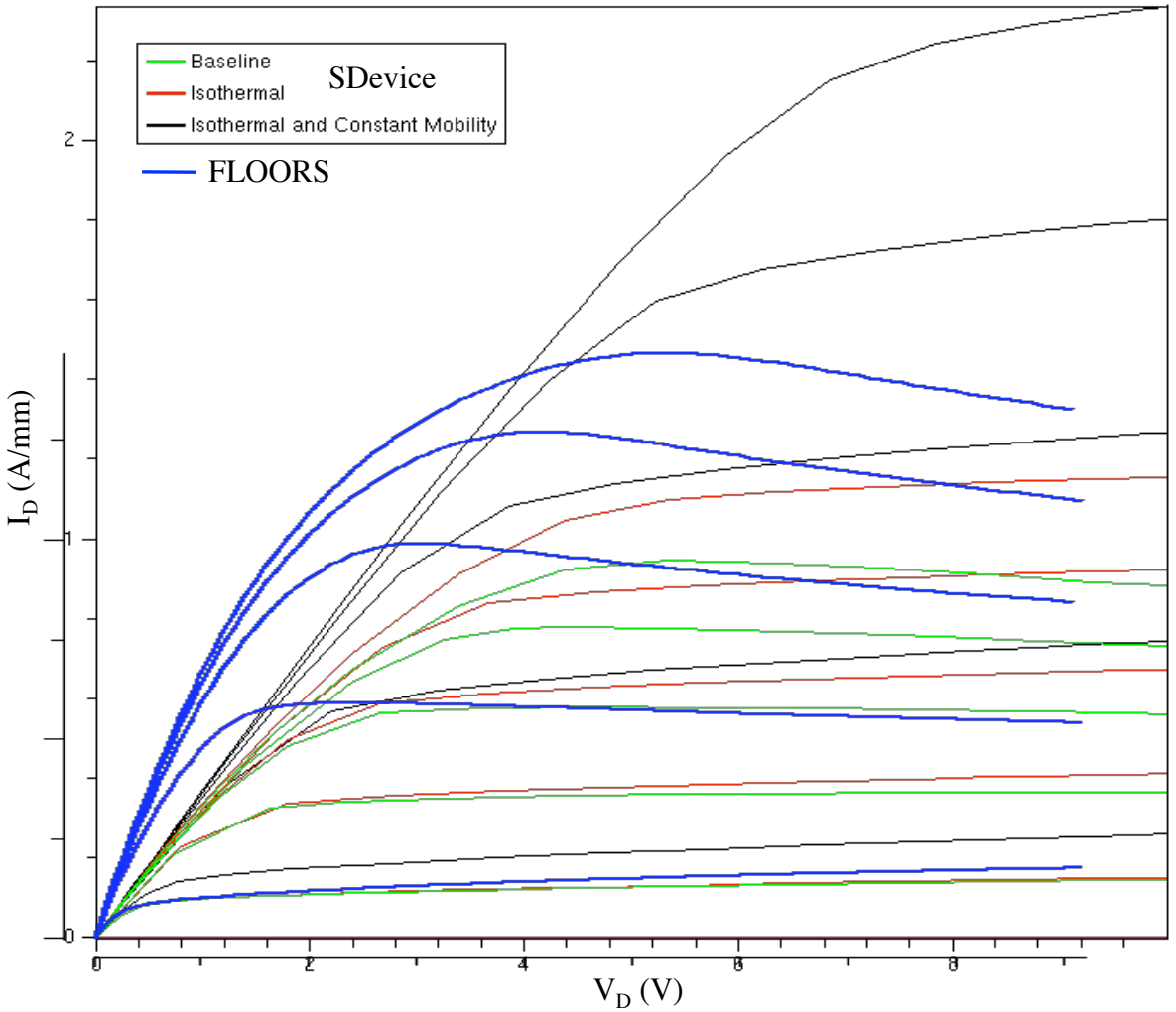
FLOORS: $$\mu = \frac{\mu_0(T,\,N) + v^{sat}\dfrac{E^{n1-1}}{E_c^{n_1}}}{1 + a\left(\dfrac{E}{E_c}\right)^{n_2} + \left(\dfrac{E}{E_c}\right)^{n_1}}$$

(from Farahmand et al, IEEE Trans. Elec. Dev., Mar 2001)

- Other parameters
  - GaN and AlGaN E_G, interface charge tweaked to match Heller

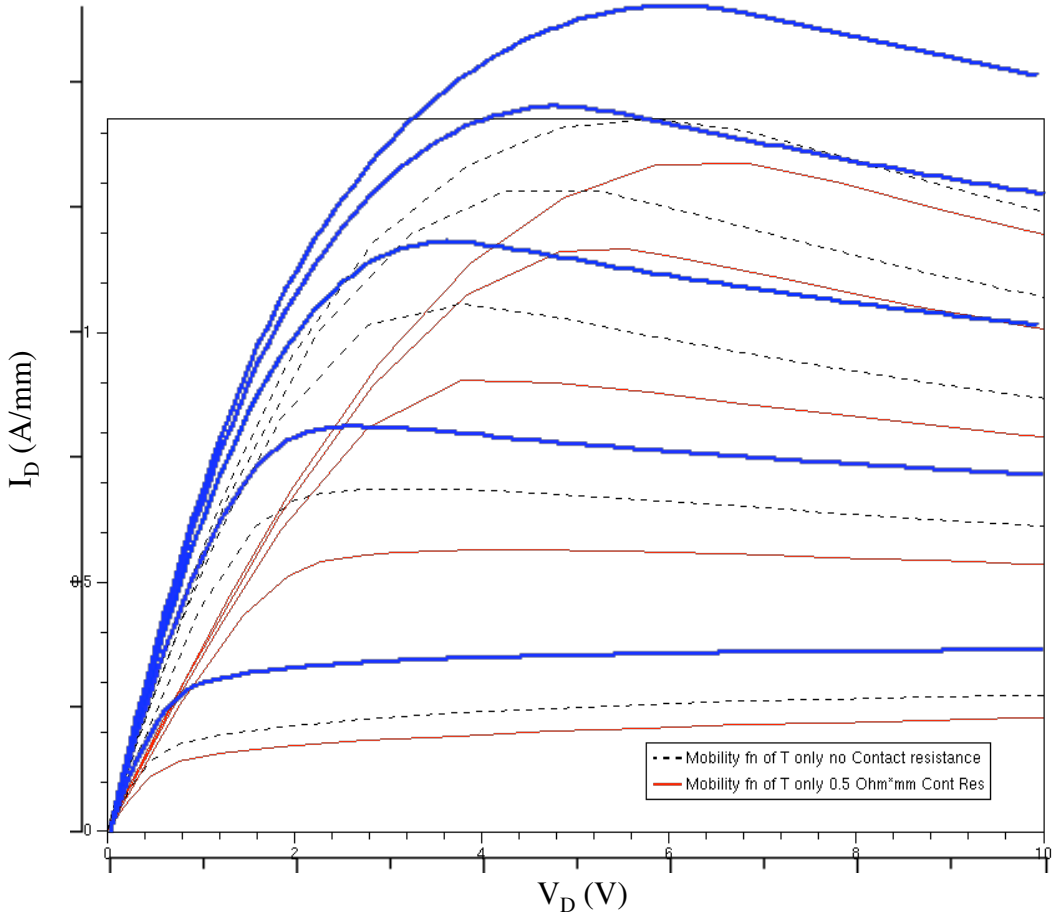
IV Comparison with New Models

- Compare green (SDevice) to blue (FLOORS)
- FLOORS now overshoots SDevice models by ~50%
- Contact resistance difference accounted for through bias changes



IV Comparison with No Contact Resistance

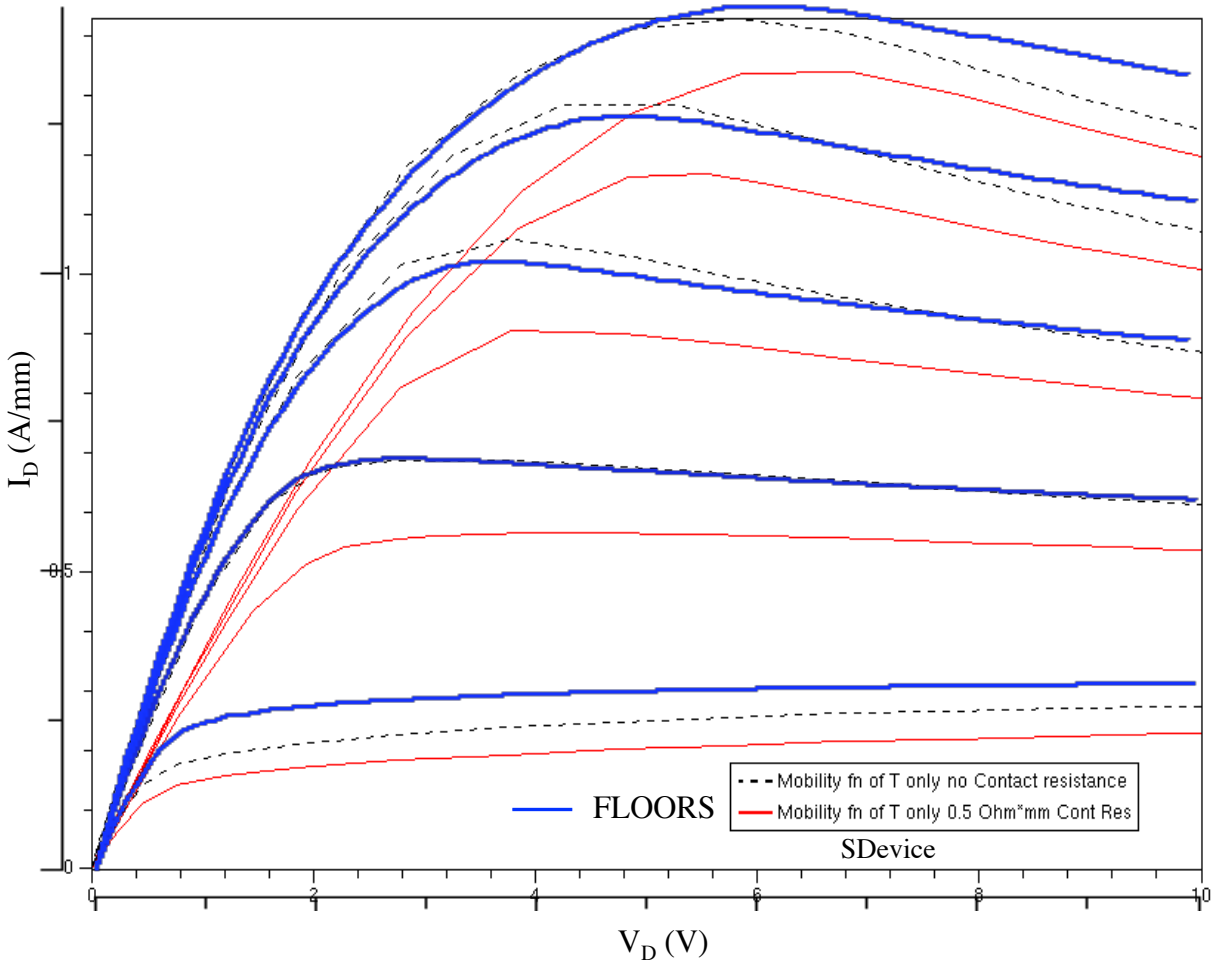
- Simpler model comparison
  - Temperature dependent mobility only
    - Low field
    - Helps to distinguish which mobility is causing the bulk of the mismatch
    - Better match
      - High field mobility is most of calibration issue
  - Eric ran SDevice simulations with no contact resistance
    - Compare black-dashed (SDevice) to blue (FLOORS)
    - Extremely good match with curve shape and V_D values
    - Contact resistance development needed in FLOORS



Best Calibration for Simplest Model

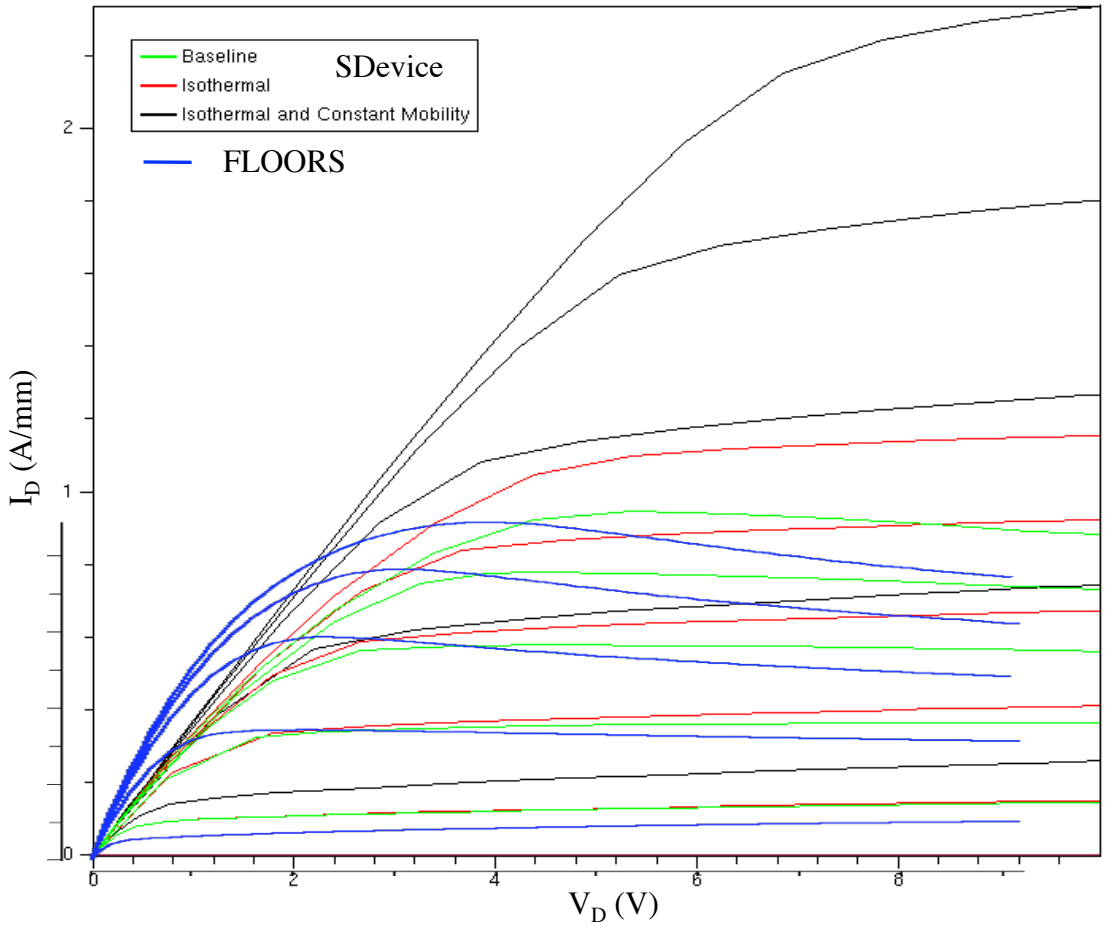
- Compare black-dashed (SDevice) to blue (FLOORS)
- Changing numerator in GaN low field mobility equation produces good fit:

$$\frac{1450}{\left(\frac{T}{300}\right)^{1.88}}$$



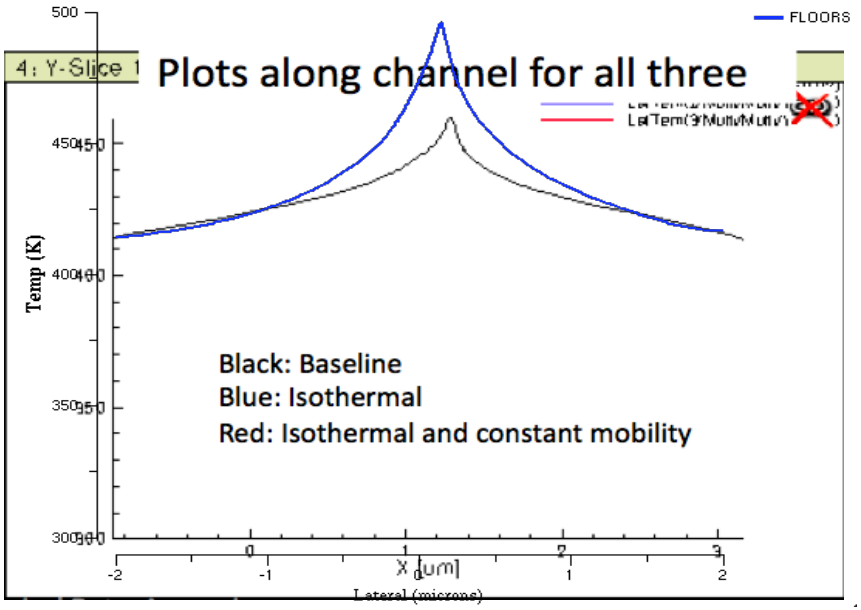
Best Calibration to Full Model

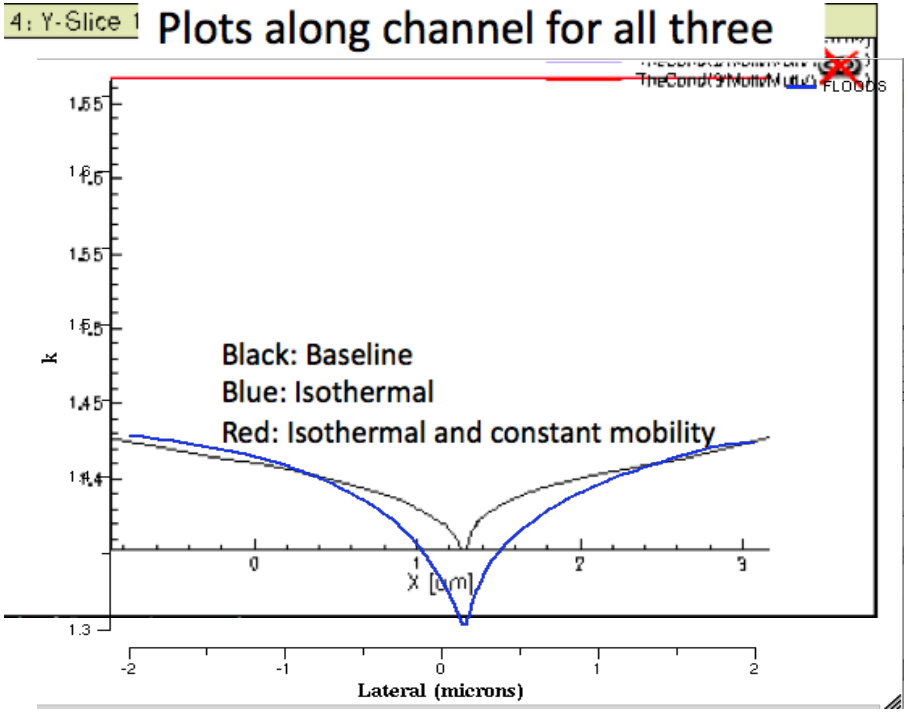
- Compare green (SDevice) to blue (FLOORS)
- Using Eric's low field mobility equations with numerator at 1450 instead of 1630
- Using Farahmand's high field mobility
- I_D is a very good match
- With contact resistance included in both simulations, still a V_D offset of ~25%



Parameter Comparison between SDevice and FLOORS

— FLOORS — SDevice

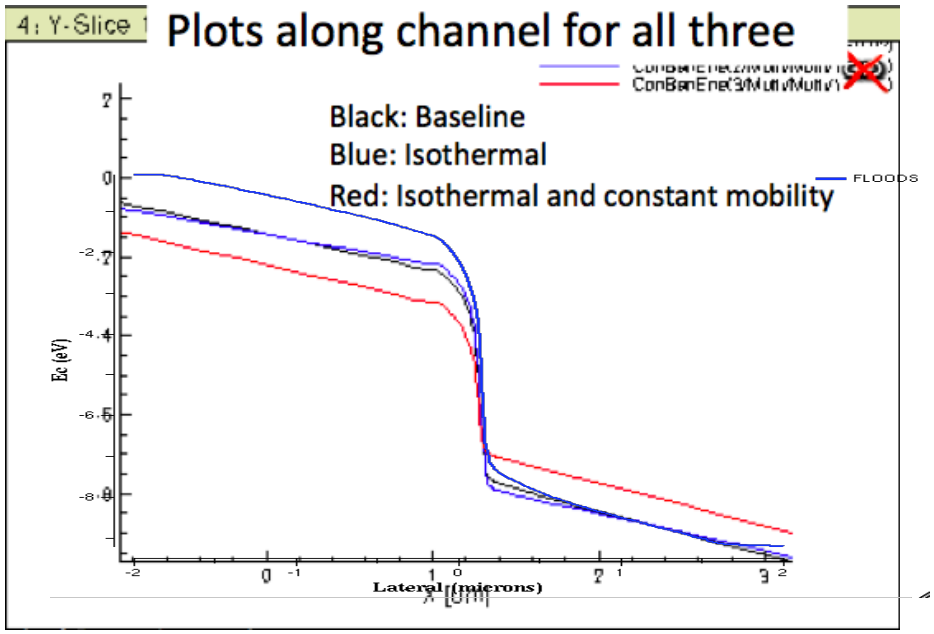


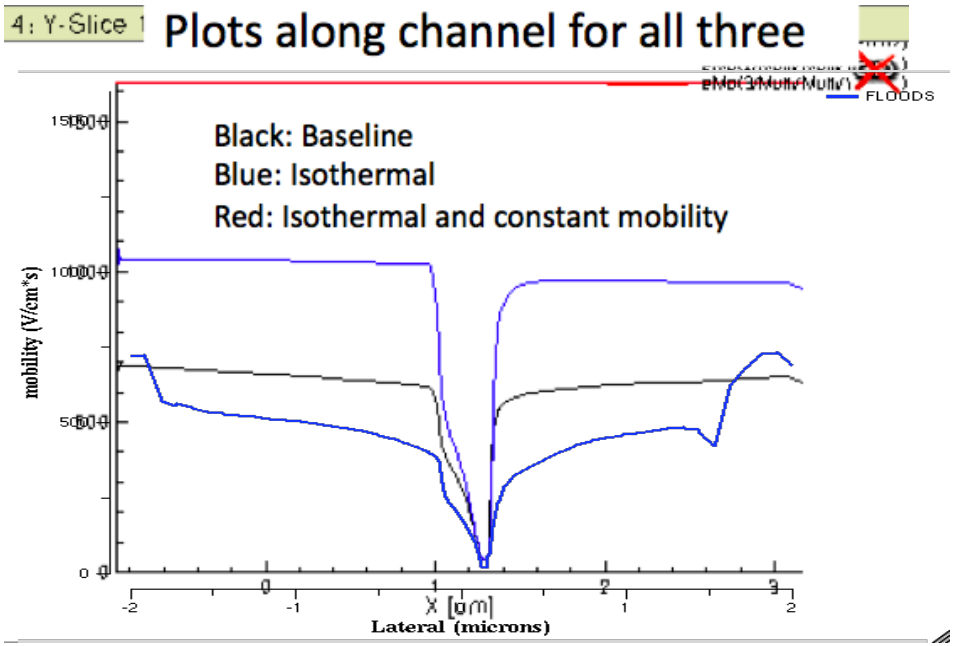


- Temperature is ~8% (35 °K) higher under gate contact in channel
- Accordingly, thermal conductivity is lower at same location

Parameter Comparison between SDevice and FLOORS

— FLOORS — SDevice





- E_C is good match, ~0.5 eV higher on left side of device

- Mobility is ~25% lower along most of channel

Current and Future Work

- Current work
  - Continuing calibration
    - Effect of high field mobility
    - Difference in parameters under gate
  - Developing contact resistance capabilities
  - Adding traps/defects in AlN
  - Expanding collaborations with materials characterization group
- Future work
  - Simulating accelerated lifetime testing